MEASUREMENT OF THE THERMAL CONDUCTIVITY OF GASES AT HIGH PRESSURE

BY

JOHN MILTON LENOIR

B.S., University of Illinois, 1942
M.S., University of Iowa, 1947

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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Summary

An apparatus was constructed for measuring thermal conductivities of gases at high pressure to a precision of 1½ percent for low values of thermal conductivity and to a precision of 3 percent for high values of thermal conductivity. Results with nitrogen agreed with the previous findings of Vargaftik (9), who measured values up to 90 atmospheres. Pressure-thermal conductivity isotherms for nitrogen, methane, argon, hydrogen, helium, ethylene, and carbon dioxide have been experimentally determined from 1 to 200 atmospheres pressure. The correlation developed by Comings and Nathan (2), was found to give good agreement with the measured values, except in the region near the critical state, where the correlation predicted low values.

Historical

The thermal conductivity of gases has been measured at atmospheric pressure by others using the Schleiermacher device (7), an apparatus consisting of an electrically heated wire centered inside a tube. A measured quantity of heat is caused to flow from the wire, through a test gas layer, to the surrounding walls of the tube, with wall and wire temperatures being measured. Corrections for radiation and heat flow along the wire to the ends of the apparatus are required, and convection in the gas must be avoided. Various investigators (4,5) have shown that convection can be prevented if the fluid is placed between parallel walls sufficiently close together, and if temperature difference across the gas layer is small. Vargaftik (9) and Sellschopp (6) applied the Schleiermacher device to measure the thermal conductivity up to 90 atmospheres pressure using thin gas layers of 0.014 and 0.010 inches respectively. The tendency for convection increases rapidly

with increased pressure, and Sellschopp found that some of his results were invalid due to convection. Neither investigator was able to measure the gas thickness to a sufficient accuracy, it being necessary to calibrate their apparatus by measurements at atmospheric pressure with gases of known thermal conductivity. Because of the difficulty of making and measuring with sufficient accuracy a gas layer of thickness less than 0.010 inches it was considered necessary to employ a design of apparatus which would not depend on knowing the gas layer width precisely.

Experimental

The thermal conductivity apparatus consisted of concentric steel tubes, of 30 inches length, with a 4 inch maximum external diameter, with two annular gas layers, and provision for measuring temperatures at various points in the apparatus by means of iron-constantan thermocouples. Heat was caused to flow across these concentric tubes and gas layers from hot water on the outside to cold water on the inside, the water temperatures being held constant by forced circulation from two thermostated reservoirs. The temperature differences could be measured across the outer series of steel tubes and an outer gas layer, and across an inner series of tubes and a gas layer. In this way the apparatus consisted of an outer thermal resistance, and an inner thermal resistance, with the heat flowing through these in series under steady state conditions. The gas to be measured was part of the inner thermal resistance, and was confined in an annular layer 0.008 inches thick with a smaller diameter of 0.653 inches. The steel walls were carefully finished and highly polished. The inner tube was centered in the outer by a light reflection technique. The confining walls were made thick enough to withstand the high pressures. The gas in the outer layer was at atmospheric pressure.

The outer thermal resistance was independent of the pressure used in the inner gas layer. The inner thermal resistance, which contained the test gas, was a function of this pressure.

The ratio of the temperature difference across the inner layers to the temperature difference across the outer layers was shown to be a linear function of the reciprocal of the thermal conductivity of the test gas. This would be expected if the heat flow through the inner and outer layers of thermal resistance was the same, if radiation errors were negligible, if the apparatus was sufficiently symmetrical so that irregular heat flow patterns were not significant, and if convection was absent. To minimize radiation error and to aid in preventing convection a temperature difference across the gas layer in the range of 1 to 5° F. was used. This small difference also simplified the determination of the temperature of the gas.

The exact relation between the temperature difference ratio and the reciprocal of the conductivity was obtained with the test gas layer filled with gases of known thermal conductivity at atmospheric pressure. The calibrating gases used were carbon dioxide, nitrogen, methane, and helium. Calibration of the apparatus in this way resulted in linear plots of the temperature difference ratio against the reciprocal of the thermal conductivity, and showed that errors from radiation and non-symmetry were negligible. The equality of heat flow through both resistance layers at the midpoint was maintained by keeping the temperatures at the ends of the apparatus equal to the temperature at the midpoint, by supplementary heating or cooling at the ends, thus preventing longitudinal heat flow. For cases where longitudinal heat flow was not completely eliminated a small correction was applied. With increased pressure the gas layer thickness increased very slightly because of the strain in the metal walls. A correction was applied for this based upon stress-strain relationships in tubes (8).

Results And Discussion

Measurements of thermal conductivities were made from 1 to 200 atmospheres pressure. The precision of measurement was 1½ percent at values of thermal conductivity less than 0.02 Btu/ hr. ft. °F. The precision at higher values gradually decreased and was 3 percent at a conductivity of 0.10 Btu/hr.

ft. °F. The agreement with the previous data of Vargaftik for nitrogen was excellent.

A summary of the data is presented in Table I, based upon smoothed values.

TABLE I

PRESSURE — THERMAL CONDUCTIVITY DATA

Gas	Temperature °F	Pressure Atmospheres	Thermal Conductivity Btu/hr.ft.°F.
Nitrogen	106	1.0	0.0157
		50.0	0.0169
		100.0	0.0185
		150.0	0.0203
		200.0	0.0221
Methane	106	1.0	0.0210
		50.0	0.0234
		100.0	0.0268
		150.0	0.0311
		200.0	0.0362
Argon	106	1.0	0.0108
		50.0	0.0119
		100.0	0.0133
		150.0	0.0149
		200.0	0.0166
Helium	109	1.0	0.0899
		50.0	0.0921
		100.0	0.0942
		150.0	0.0963
		200.0	0.0985
Hydrogen	109	1.0	0.112
		50.0	0.115
		100.0	0.119
		150.0	0.125
		200.0	0.132

Gas	Temperature °F	Pressure Atmospheres	Thermal Conductivity Btu/hr.ft.°F.
Ethylene	106	1.0	0.0128
		50.0	0.0173
		100.0	0.0372
		150.0	0.0470
		200.0	0.0551
Ethylene	153	1.0	0.0148
		50.0	0.0181
		100.0	0.0276
		150.0	0.0384
		200.0	0.0456
Carbon Dioxide	106	1.0	0.0104
		50.0	0.0136
		100.0	0.0450
		150.0	0.0528
		200.0	0.0605
Carbon Dioxide	134	1.0	0.0111
		50.0	0.0136
		100.0	0.0250
		150.0	0.0445
		200.0	0.0512
Carbon Dioxide	153	1.0	0.0116
		50.0	0.0142
		100.0	0.0218
		150.0	0.0376
		200.0	0.0466

To determine whether convection existed a series of measurements were made at larger values of temperature difference across the gas layers. If convection existed it would be expected that a larger value of conductivity would have been obtained with the larger temperature difference. This was not observed, indicating the absence of convection. As a further check, the criterion of Kraussold (4), that the

product of the Grashof and Prandtl numbers should not exceed 600 was applied. This also showed convection to be absent although the conditions for incipient convection were closely approached in some cases.

The results were compared with the generalized correlation developed by Comings and Nathan (2) from the theoretical equations of Chapman (1) and Enskog (3). The correlation predicted values of thermal conductivity to within 4 percent of the measured values, on the average, and appeared to give a mean value between the various gases. In the region near the critical state the correlation gave low values to a maximum extent of 20 percent.

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VITA

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